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H. M. Agnew
H. L. Anderson
G. Miller
J. H. Roberts
M. D. Whitaker
E. O. Wollan

Argonne National Laboratory

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Source II—Experiments in a Water Tank

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ABSTRACT

The number of neutrons emitted by a Ra+Be source was measured by integrating the thermal neutron activity of a standard detector in a water tank. It was found that the number of neutrons emitted by Source II (10 g of Be mixed with 1 g of Ra) is 14.0×10^6 neutrons per second.

* * * * *

If a source of neutrons is placed in a large tank of water, all the neutrons will be slowed down to thermal energies and ultimately captured as thermal neutrons by hydrogen. In the experiments described herein, the number of neutrons emitted by the source is measured by integrating the thermal neutron intensity throughout the water tank and standardizing the detector in such a way that the intensities can be interpreted in absolute units. The method is essentially that which was carried out by Amaldi and Fermi[1] and differs only in the manner of the standardization of the detector.

THE DISTRIBUTION OF THERMAL NEUTRONS* IN A WATER TANK.

The experimental arrangement is shown in Figure 1. The Ra+Be source could be inserted in the water or withdrawn from the water into a lead shield by manipulating a string attached to a pulley. Foils of indium 1.69 g over an area of 3 x 6.4 cm^2, could be suspended in the water tank at different distances from the source. The detector was held and completely covered by a holder, which was either 0.030 g/cm^2 of aluminum or 0.45 g per cm^2 of cadmium. Measurements were taken with the indium foil either in the aluminum holder or in the cadmium holder at various distances from the source. The irradiation was started by dropping the source from its lead shield above the water to a fixed position in the water. The irradiation was terminated by returning the source back into the lead shield. These operations could be executed within a fraction of a second. The activity of the foil was measured after a delay of at least three minutes (so as to be sure that the 13-second period of indium had decayed) by wrapping the foil inside a cylindrical brass holder, which could be slipped over a Geiger Mueller counter in a definite position. The activity observed was always reduced to initial activity of the 55-minute life in counts per minute after infinite irradiation.

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* The term thermal neutrons is somewhat loosely applied in this paper. Actually, we are dealing with those slow neutrons which are strongly absorbed by cadmium. In water, the energy distribution of these neutrons lies somewhat higher than for neutrons in thermal equilibrium.

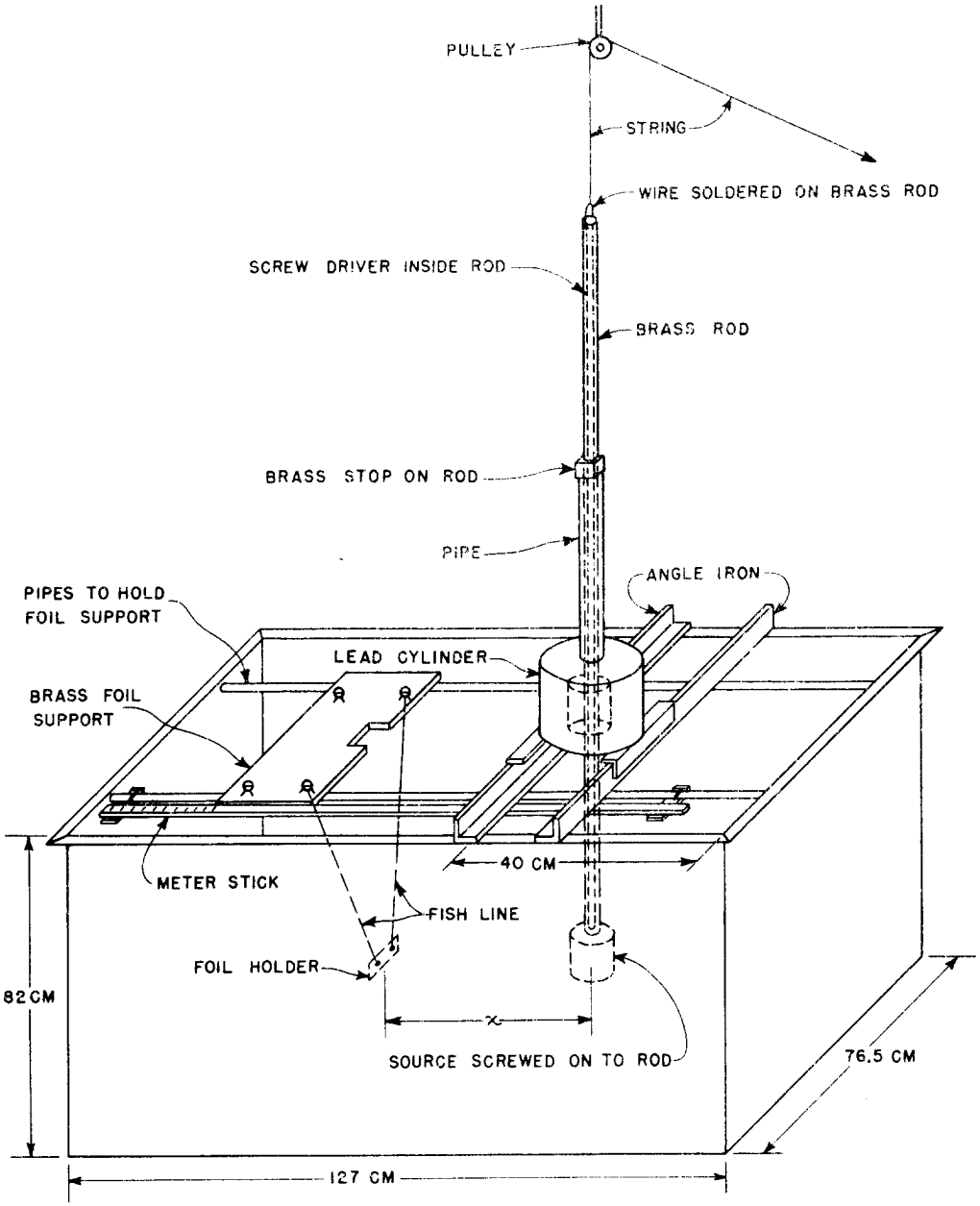
PULLEY
STRING
WIRE SOLDERED ON BRASS ROD
SCREW DRIVER INSIDE ROD
BRASS ROD
BRASS STOP ON ROD
PIPE
ANGLE IRON
PIPES TO HOLD FOIL SUPPORT
LEAD CYLINDER
BRASS FOIL SUPPORT
40 CM
METER STICK
FISH LINE
FOIL HOLDER
82 CM
SOURCE SCREWED ON TO ROD
76.5 CM
127 CM

Figure 1.

The data obtained from these measurements are tabulated in Table 1.

Table 1.*

$\sqrt{r^2}$	$A\bar{r}^2$	
	1.07 Cd	No Cd-1.07 Cd
4	1.297×10^6	8.40×10^6
6	1.880	14.08
8	1.931	17.41
10	1.661	17.78
12	1.364	16.25
14	1.113	14.21
16	.899	11.85
18	.725	9.57
20	.586	7.64
22	.471	6.13
24	.381	4.98
26	.310	4.15
32.2		2.32
38.2		1.24
50.0		.38

* In column 1, the root mean squared distance from the source to the foil is given. In column 2, 1.07 A(res) $\bar{r}^2$, the value of the saturation activity in counts per minute times the mean squared distance multiplied by 1.07 in counts per minute cm^2 obtained with cadmium is given. In column 3 is given the value of $A\bar{r}^2$ due to thermal neutrons. The values given there have been calculated by subtracting the values in column 2 from the corresponding values taken without Cd (the factor 1.07 takes into account the absorption of the resonance neutrons of indium by cadmium.)

For large distances the value of $A\bar{r}^2$ for thermal neutrons may be represented by the formula

$$A\bar{r}^2 \times 10^{-6} = 56.7\, e^{-.100\, r} \text{ c/m} \times \text{cm}^2 \qquad (1)$$

The value of the integral $4\pi \int_2^\infty A\bar{r}^2\, dr$ as calculated from these data is

$$3.84 \times 10^9 \text{ c/m} \times \text{cm}^3$$

The region from r = 0 to 2 cm was occupied by the source and was not included in the integral.

STANDARDIZATION OF DETECTORS

The indium detectors were standardized so that their activities could be interpreted as neutron densities. The standardization was carried out as outlined in report CP-226. As pointed out there, a direct comparison of indium with a boron trifluoride counter is not valid, due to the presence of the strong indium resonance at 1.35 ev. Actually, manganese dioxide detectors were compared with the standard BF_3 counter in a neutron beam outside paraffin as reported in CP-226. A comparison of the thermal neutron activity of these MnO_2 detectors, with the indium detectors, was carried out at several positions in the water tank. The ratio of the thermal neutron activities was found to be

$$\frac{A(Mn)\ c/min/g}{A(In)\ c/min} = .1964 \tag{2}$$

independent of the position.

It follows that the number of neutrons traversing the indium detector per second may be computed from the relation

$$nv = 0.149\ A(In)\ \frac{neutrons}{sec \times cm^2} \tag{3}$$

NUMBER OF NEUTRONS EMITTED FROM SOURCE II

The number, Q, of neutrons emitted per second may be equated to the number of thermal neutron captures by hydrogen* throughout the water tank

$$Q = \int_V nv\,\sigma_{1cc}\,dV \tag{4}$$

where σ_{1cc} is the capture cross section of 1 cc of water. Using the value 1940 for the ratio of the capture cross section of boron to hydrogen, as measured by Frisch, Halban, and Koch,[2] and the value 411 cm^2 per mole for the capture cross section of boron,[3] for neutrons having the average velocity ($\bar{v}$) of the Maxwell distribution, the value $\sigma_{1cc}(\bar{v})$ may be taken to be 0.0235 cm^2. From this and the above results it follows that

$$Q = 3.84 \times 10^9 \times 0.149 \times 0.0235 \times 1.02 = 13.7 \times 10^6\ neut/sec \tag{5}$$

The factor 1.02 takes into account the lowering of the neutron density in the neighborhood of the manganese detector due to its neutron absorption. This is the number of neutrons which are absorbed per second in the water. About 2% of the neutrons are absorbed in the brass container and by the bromine of the radium bromide. It follows that the number of fast neutrons emitted by Source II is

$$14.0 \times 10^6\ neutrons/second \tag{6}$$

Source II contains 10 g of Be mixed with 1 g of Ra as radium bromide enclosed in a cylindrical brass container of overall length 5.3 cm and a diameter of 3.05 cm. The brass container weighs 110 grams.

THE ABSOLUTE NEUTRON DENSITY IN A WATER TANK

A convenient way of representing the results obtained in the above experiments is to plot the ratio $\frac{nv}{Q}$ as a function of r. This function is plotted in Figure 2. The function f(r) gives the fraction

*The capture probability per unit time for hydrogen, boron, and manganese is independent of neutron energy in this energy region as has been demonstrated by Manley, using the slow neutron velocity selector (c-19, C-211).

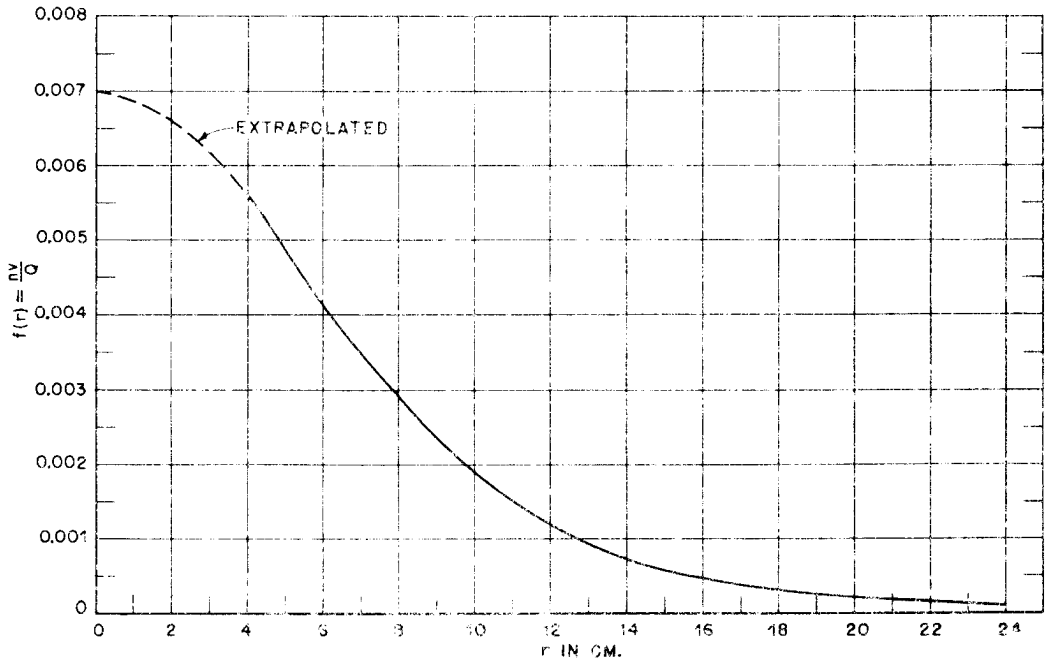

Figure 2. The fraction of neutrons emitted by a Ra-Be source which pass across 1 cm^2 in water as thermal neutrons.

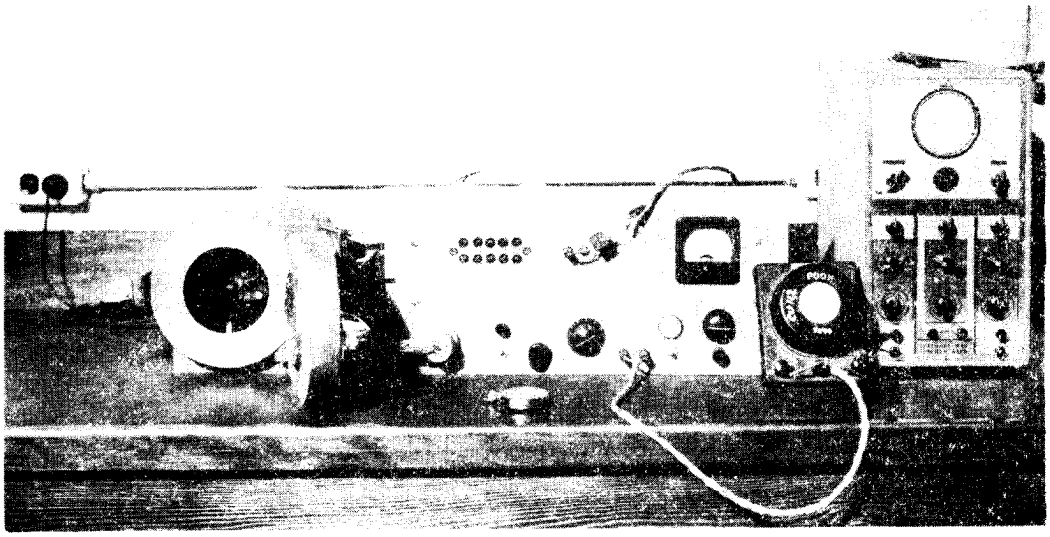

Figure 3.

of neutrons emitted by a Ra+Be source which pass across 1 cm^2 in water as thermal neutrons. Thus, if the number of neutrons emitted by a source is known, the number of thermal neutron captures per second γ by a substance whose capture cross section is σ is given by

$$\gamma = Q \sigma f(r)$$

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1. Amaldi, E. and E. Fermi, Phys. Rev. 50:899 (1936).

2. Frisch, O. R., H. v Halban, and J. Koch, Kgl. Danske Videnskab. Selskabs. 15(10) (1938).

3. C-74.